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A R M S T R O N G

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EVALUATION OF MINILATOR USE ON PTLOX AND C-141 OXYGEN SYSTEMS

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This report has been reviewed and is approved for publication.

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13. ABSTRACT (*Maximum 200 words*)

The Minilator is a compact device used to deliver a constant flow of oxygen at a maximum of 15 liters per minute (LPM). It is capable of delivering oxygen for one to five patients simultaneously. The purpose of this study was to validate its air worthiness and find the maximum number of minilators that can be used with the 10 liter PTLOX and C-141 LOX supply systems. It also established that a minilator cannot be used in line with a ventilator. It was determined that a ventilator with a requirement of 50±5 should not be supported by a gas supply from a hose length exceeding 400 feet. For optimum performance of the ventilator, hose length should not exceed 100 feet. Four people being administered 15 LPM can be supported from one 10 liter PTLOX. Thirty-eight people being administered 15 LPM can be supported from the C-141 liquid oxygen system. Any combination of minilators can be used as along as the recommended parameters stated in this study are followed.

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TABLE OF CONTENTS

List of Figures

List of Tables

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BACKGROUND

HQ Air Mobility Command (AMC) requested Human Systems Center evaluate the Life Support Products (LSP) Minilator. The minilator was first introduced into the aeromedical evacuation environment during Desert Shield/Desert Storm for use on aeromedical evacuation aircraft. Because formal testing to determine air worthiness had not been done, the Crew Technology Division was tasked to complete the evaluation process on this device and determine safe operational parameters.

HQ AMC requested validation on the air worthiness of the minilator and posed questions regarding the maximum number of minilators for use with the 10 liter PTLOX and the C-141 LOX supply, and the number of ventilators that can be operated through the minilator.

UNIT DESCRIPTION

The LSP Minilator is compact, lightweight, and simple-to-operate. Given a constant pressure source, the minilator is a constant flow device that can provide oxygen at flows up to 15 liters per minute (lpm) for one to five patients simultaneously. The unit is comprised of an anodized aluminum manifold with check valves and threaded barbed fittings with metered orifices. It can be attached directly to an oxygen regulator capable of delivering 40 to 90 psig. The company manufactures other models that provide varying flows. For the purpose of this study, we evaluated Model no. 419-050, an aluminum manifold with 5 O_2 DISS check valves and 5 interchangeable 15 lpm orifices. The unit is 1" x 6" x 7.5" and weighs 13.5 ounces.

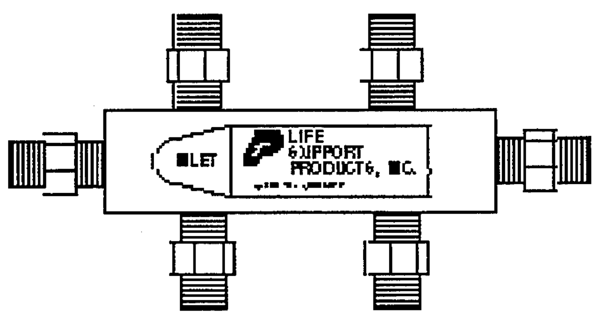

Figure 1. Minilator, model no. 419-050.

TEST METHODS

Variables that contribute to the complexity of evaluating or establishing limitations for any device used to direct flow originating from a liquid source include the system's ability to convert the liquid to a gas and any significant drop in line pressure between two points. This study assumes that the phase change of liquid to gas is not an issue (i.e., the demand is not limited or restricted by the

phase change process.) The issue that remains to be addressed is to determine the necessary flow and pressure needed to supply oxygen to a patient.

Because the minilator is essentially a manifold with a multi-port access site, flow downstream of the minilator is regulated by the "port" size and remains constant unless the upstream pressure changes or the port becomes occluded. Aside from the removable, all-in-one, orifice/check valves, the minilator has no moving parts to wear out. Being a passive device, it is entirely dependent on the line inlet conditions. This realization requires that the focus be adjusted to that of: 1) reservoir capacities, and 2) pressure drop in line runs.

To determine the maximum number of people that can be supported from either the PTLOX or C-141 LOX system, maximum sustained flows, had to be identified. The PTLOX study conducted by aeromedical research personnel of the Systems Research Branch (Nov 1990), provided information on the maximum flow capacity of the Essex Corporation's 10 liter (L) liquid oxygen system.

For the C-141 therapeutic liquid oxygen system, Technical Order 1C-141B-1, Page 1-337, Figure 1-87, Sheet 3 of 3 "Oxygen Duration" (Atch 1) was used as a reference in determining the maximum flow. The flow was derived from data on man-hours and liters of liquid oxygen provided for each corresponding altitude.

The next step involved determining the maximum length of oxygen hose that can be used while still maintaining the pressure and flow requirements established for the treatment of aeromedical evacuation patients. This information was used to determine how far from the oxygen supply the patient can be supported and how many ventilators can be used efficiently. The theory and data for this parameter are derived empirically using the test set-up shown in Figure 2. Gas sources used included an oxygen H-cylinder and an airdyne air compressor. Air and oxygen were used to determine any limitations between the two gases. These sources were used to simulate the principal operation of the PTLOX and associated liquid oxygen systems. P1 and P2 are Bio-Tek DPM III hand-held pressure meters each set to the 35 - 100 psi range. The mechanical flow meter (FM) is the standard meter utilized by aeromedical evacuation medical crews. A Tylan (TFM) oxygen flow meter or Tylan (TFM) air-flow meter corresponded to the gas source used. The electronic flow meters produce a linear 0-5 Vdc analog output over a calibrated range of 0-50 liters per minutes (lpm). Voltages were measured with a Fluke multimeter and recorded on a data collection sheet.

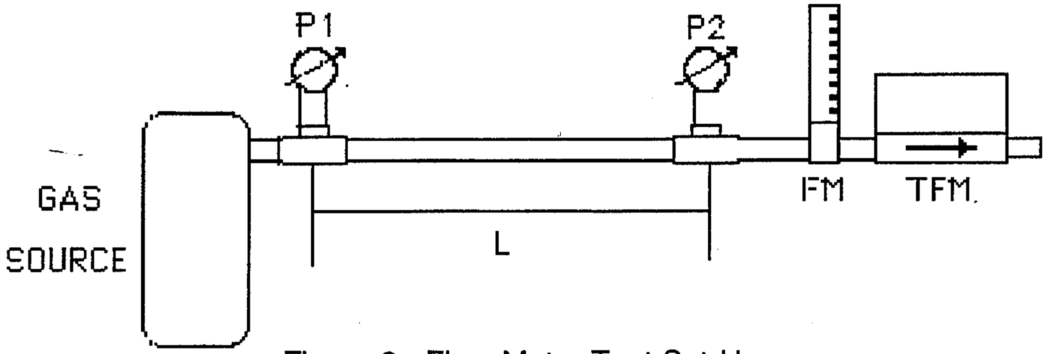

Figure 2. Flow Meter Test Set-Up.

The flow meter was set and maintained at 15 lpm for all portions of flow testing and length (L) was initially represented by a 50 ft oxygen hose. The gas source was turned on and the system allowed to stabilize. Pressure was recorded at P1 and P2. The drop in pressure (ΔP) over the hose length was calculated by subtracting the pressure at P2 from the pressure at P1. The digital flow meter was used to verify that flow remained constant. Fifty ft oxygen hose lengths were then added and the above steps repeated after each addition, up to 650 ft, providing 13 data points.

From these data an equation was developed to best represent the data points. Extrapolation was used to determine the maximum length of hose for either an air or oxygen source.

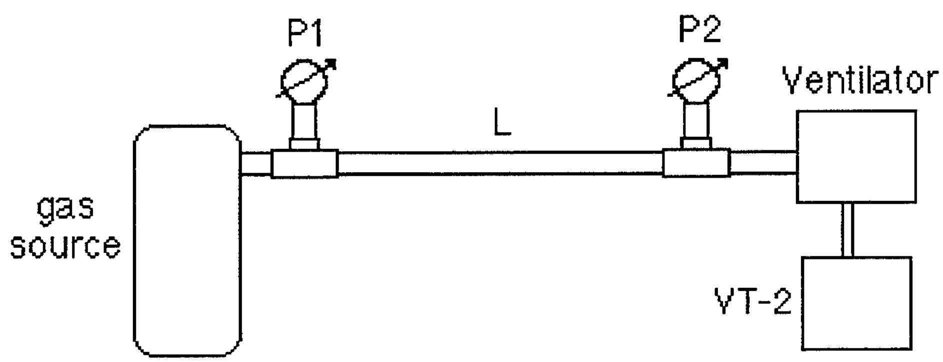

Figure 3. Ventilator Test Set-Up.

The third step involved determining the maximum length of oxygen hose that can be used while still maintaining the pressure and flow requirements of a ventilator requiring a 50±5 psi gas source. This ventilator portion of testing was accomplished IAW the test set-up shown in Figure 3. This set-up was used to determine whether a ventilator can operate at a setting of 20±5 breaths per minute (bpm) and a tidal volume of 1 liter. The ventilator setting is representative of a consistently heavy demand on a gas source over a given length of hose. An

Omni-Vent Series D ventilator was used in this study. The Bio-Tek VT-2 ventilator tester monitored the output of the ventilator in the status test mode. In the status test mode the VT-2 tester displayed the bpm and tidal volume after every two ventilation cycles.

The ventilator was set to 20±5 bpm and 1 liter tidal volume and was not readjusted after any changes in the oxygen hose length. In Figure 3, L was initially represented by a 50 ft oxygen hose. The gas source was turned on and the system allowed to stabilize. Pressure was recorded at P1 and P2. The drop in pressure (ΔP) over the hose length was calculated (P2 - P1). The results of the status test were recorded. Fifty ft oxygen hose lengths were then added and the above steps repeated after each addition, up to 650 feet.

These data were used to determine the maximum allowable hose length that can be used in conjunction with a ventilator requiring a 50±5 psi gas source.

TEST RESULTS

The 10 L PTLOX has a maximum flow of 60 lpm, as specified by the manufacturer, and confirmed by a previous study. The limiting factor that defines the maximum flow is the system's inability to adequately heat the liquid oxygen and convert it to gas for demands higher than 60 lpm. This maximum flow can then be manipulated to determine the system's ability to accommodate various combinations of flows and the number of people requiring oxygen. The conclusion section of this paper illustrates this application.

The C-141 liquid oxygen system has a maximum capacity of 574.86 lpm. Analysis of information about capabilities of the C-141's oxygen system in what is defined as a "worst case" scenario determined the upper limits of the flow capacity. This analysis involved the Oxygen Duration graph from Technical Order 1C-141B-1, Page 1-337, Figure 1-97, Sheet 3 of 3. Essentially, this graph depicts the number of man-hours available for a specific amount of LLOX at a certain altitude. We defined a scenario having a low amount of LLOX, (30 LLOX), and high altitude, (35,000 ft). Normally, the C-141 will have more LLOX and be at a lower altitude. The Oxygen Duration graph is based on 143 people.

In this graph (Atch 1), manhours of oxygen remaining is shown as a function of altitude for various quantities of oxygen stored. By finding the intersection between the altitude and the line defining how many liters of LOX you have, we read the value off the Y-axis to determine how many man-hours were available (Step 1). By dividing the man-hours by the number of people that need to "breathe" off the system we determined how long the supply of oxygen would last (Step 2). Gas flow per hour is calculated by dividing the amount of gaseous oxygen by the time (Step 3), and converted to a flow rate per minute (Step 4). This is the total flow for the entire system, not per person.

In the next few equations, we used the steps above to arrive at the 575 lpm maximum capacity flow.

Given: 35,000 ft, 30 LLOX, 100 Man-Hrs, 143 people

1. Calculate the number of liters of oxygen ($LO_2(g)$) in gas by using the following relationship - 1 LLOX = 804 $LO_2(g)$.
   (30 LLOX) (804) = 24,120 $LO_2(g)$

2. Calculate the hours of oxygen available
   100 man-hours/143 passengers = 0.6993006 hrs

3. Calculate flow rate
   24,120 $LO_2(g)$/(0.6993006)hrs = 34491.604 liters/hrs

4. Calculate the number of liters of oxygen used per minute
   (34491.604liters/hrs) / 60 minutes/hr = 574.86 lpm

Table 1 provides the results of calculations performed on 8 data points obtained from Technical Order 1C-141B-1, Page 1-337, Figure 1-87, Sheet 3 of 3 "Oxygen Duration". This information was necessary to prove that for any altitude there is a corresponding lpm flow rate for the system, the worst case being represented by the least number of available man-hours, low LLOX, and high altitude. The $LO_2(g)$/minute results obtained do in fact correspond, ± 10%, to the respective altitudes from which they were derived. This ± 10% error is mainly due to an inability to accurately read data from the graph provided in the technical order. The maximum derived lpm flow rate of 4.02 lpm, occurs at 35,000 ft. This number was used to determine the maximum demand flow on the system for the 143 personnel provided by the example.

Given:	liters gaseous oxygen $LO_2(g)$	$LO_2(g)$ / minute	maximum flow for system - lpm
35,000 feet 150 LLOX 550 Man-Hrs	120,600	3.65	523 lpm
35,000 feet 30 LLOX 100 Man-Hrs	24,120	4.02	575 lpm
30,000 feet 150 LLOX 675 Man-Hrs	120,600	2.98	426 lpm
30,000 feet 110 LLOX 500 Man-Hrs	88,440	2.95	422 lpm
25,000 feet 150 LLOX 800 Man-Hrs	120,600	2.15	359 lpm
25,000 feet 10 LLOX 50 Man-Hrs	8,040	2.68	383 lpm
15,000 feet 150 LLOX 1350 Man-Hrs	120,600	1.49	213 lpm
15,000 feet 50 LLOX 450 Man-Hrs	40,200	1.49	212.9 lpm

Table 1. Results derived from calculating T.O. data.

Tables 2 and 3 show the data used to derive the graphs in Attachments 2 and 3. There were no problems with either the air or oxygen portions of testing. The results obtained show that there is no significant difference of drop in pressure, ΔP, over an equivalent oxygen hose length between air and oxygen.

Length (L) feet	Pressure (P1) psi	Pressure (P2) psi	Digital Flow Meter (TFM) - lpm	Change in Pressure (ΔP) - psi
50	51.8	52.3	14.1	.5
100	51.5	52.1	14.1	.6
150	51.4	52.2	14.3	.8
200	51.3	52.2	14.3	.9
250	51.0	52.0	14.2	1.0
300	50.8	52.0	14.2	1.2
350	50.7	52.0	14.1	1.3
400	50.6	52.0	14.1	1.4
450	50.4	52.0	14.1	1.6
500	50.3	52.0	14.1	1.7
550	50.2	52.0	14.1	1.8
600	49.3	51.5	13.9	2.2
650	48.1	50.8	14.1	2.7

Table 2. Air Compressor and 1/4" Oxygen Hose.

Length (L) feet	Pressure (P1) psi	Pressure (P2) psi	Digital Flow Meter (TFM) lpm	Oxygen Regulator Gauge (psi)	Change in Pressure (ΔP) - psi
50	49.0	49.5	14.8	52	.5
100	48.7	49.3	14.3	52	.6
150	48.8	49.6	14.4	52	.8
200	48.9	49.8	14.4	52	.9
250	48.8	49.8	14.5	52	1.0
300	48.8	49.9	14.5	52	1.1
350	48.6	49.9	14.5	52	1.3
400	48.5	49.9	14.5	52	1.4
450	48.3	49.9	14.5	52	1.6
500	48.3	50.1	14.5	52	1.8
550	48.1	50.0	14.5	52	1.9
600	48.0	50.0	14.5	52	2.0
650	47.2	49.8	14.5	52	2.6

Table 3. H-cylinder Oxygen Bottle and 1/4" Oxygen Hose.

The Omni-Vent ventilator and oxygen H-cylinder regulated at 50±5 psi were used to evaluate the ventilator portion of testing. It was not necessary to use the air compressor since the flow testing, Attachments 2 and 3, show that the drop in pressure is nearly identical for air and oxygen over the same oxygen hose length. Table 4 shows the results of the ventilator evaluation. The Omni-Vent could provide the 20±5 bpm at 1 liter tidal volume output given in the methods section at the maximum hose length of 650 ft because this ventilator can operate at gas source pressures in a range from 20 to 75 psi. No problems were noted with this test set-up or data collection.

Length (L) feet	Press (P1) Max psi	Press. (P1) Min psi	Press. (P2) Max psi	Press. (P2) Min psi	Breath per Minute	Tidal Volume	Change in Press. (ΔP) Max	Change in Press. (ΔP) Min
50	50.9	46.6	50.2	42.9	29.0	.825	.7	3.7
100	50.4	46.9	49.4	41.5	28.6	.840	1.0	5.4
150	49.3	47.2	47.2	40.9	28.2	.851	2.1	6.3
200	49.3	47.5	47.0	40.1	28.6	.853	2.3	7.4
250	49.1	47.6	46.0	39.5	27.6	.852	3.1	8.1
300	49.0	48.0	45.6	39.6	28.1	.863	3.4	8.4
350	49.0	48.0	45.1	38.8	27.1	.886	3.9	9.2
400	48.9	48.4	44.0	38.6	26.7	.924	4.9	9.8
450	48.9	48.4	43.4	37.5	26.7	.903	5.5	10.9
500	48.9	48.4	43.0	36.8	26.2	.915	5.9	11.6
550	49.0	48.8	42.6	36.3	25.7	.930	6.4	12.5
600	49.0	48.9	42.2	35.7	24.4	.956	6.8	13.2
650	49.0	47.8	41.8	32.0	21.7	1.058	7.2	15.8

Table 4. Ventilator Test Results.

DISCUSSION

In this study we used an Omni-Vent ventilator to determine the maximum length of hose that could be used and still maintain 50±5 psi. The Omni-Vent performed at the desired output at 650 ft oxygen hose length even though the pressure was not maintained. This is due to the fact that the Omni-Vent is designed to operate at a lower gas pressure. A pressure of 50±5 psi could not be maintained during this study beyond the 400 foot oxygen hose length. (See P2 max psi @ 400 feet.) A separate study should be performed to evaluate other ventilators to determine operational limitations.

Our tests show that up to 650 ft of oxygen hose can be used to provide 15 lpm without exceeding a pressure drop of 3 psig. The PTLOX has one regulator that regulates flow to three external outlets. It can only accommodate a total of

650 ft of oxygen hose. The C-141 liquid oxygen system has 7 independent outlets that can accommodate 650 ft of hose at each outlet.

A written specification states that 15 lpm, maximum, be provided to each patient flying on board an aeromedical evacuation aircraft. In the event this is waived, more patients can be allocated on a given system for a specified period of time. With more than 4 people to a system, however, 15 lpm may not be obtained for any individual patient. The duration of the LOX supply will still be calculated the same way that is currently used.

Example: 10 liter LOX supply; 4 people @ 15 lpm
1 liter of LOX = 804 liters of oxygen @ STP
(10)(804) = 8040 l oxygen
(4)(15) = 60 lpm
8040 / 60 = 2 hr and 14 min

RECOMMENDATION

Any combination of minilators can be used as along as the following parameters are followed. A minilator may **not** be used in line with ventilator patients. Ventilators require a higher than 15 lpm flow to operate effectively and the minilator does not provide the required flow. The regulation (MACR 164-1) regarding using only one ventilator per outlet is currently in effect. This regulation is provided to ensure the proper operation of all ventilators utilized in the aeromedical evacuation system.

From the data obtained, it was determined that the maximum length of hose that can support a ventilator with a requirement of 50±5 psi is 400 feet. For optimum performance of the ventilator, hose length should not exceed 100 feet. (see ΔP min @ 100 feet)

<u>10 liter PTLOX following 15 lpm patient requirement:</u>

- 4 people being administered 15 lpm can be supported from one 10 liter PTLOX.
- A total of 650 feet oxygen hose can be used per PTLOX.
- One ventilator patient can be supported per outlet on a 10 liter PTLOX.

<u>10 liter PTLOX **without** 15 lpm patient requirement:</u> For safety concerns, we do not recommend waiving the 15 lpm requirement.

- If the 15 lpm requirement is waived, use the following example to determine how many people can be supported from one 10 liter PTLOX:
    - add the number of lpm given to each person up to 60 lpm.
    - example: The PTLOX can support 6 people @10 lpm for a total of 60 lpm
- A total of 650 feet oxygen hose can be used per PTLOX.

<u>C-141 liquid oxygen system following 15 lpm patient requirement:</u>

- 38 people being administered 15 lpm can be supported from the C-141 liquid oxygen system.

- Recommend a maximum of 5 people per outlet, not to exceed a total of 35 over the 7 outlets.
- 650 feet of oxygen hose may be used per outlet.
- One ventilator patient can be supported per outlet on a C-141 liquid oxygen system.

C-141 liquid oxygen system **without** 15 lpm patient requirement: For safety concerns, we do not recommend waivering the 15 lpm requirement.

- If the 15 lpm is waived:
  - add the number of lpm given to each person up to 575 lpm.
  - example: The C-141 lox system can support 57 people @10 lpm for a total of 570 lpm
- 650 feet of oxygen hose may be used per outlet.

REFERENCES

1. Technical Order 1C-141B-1, Page 1-337, Figure 1-87, Sheet 3 of 3 "Oxygen Duration".

2. Life Support Products (LSP) Minilator brochure.

3. Aeromedical Research Function study dated Nov 1990 on flow capacity of the Essex Corp. 10L liquid oxygen system.